ARL 67-0099
MAY 1967
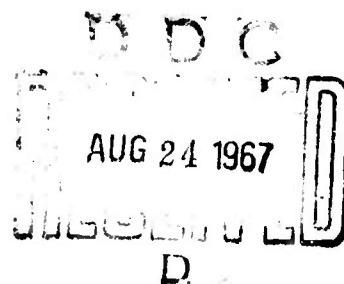
Aerospace Research Laboratories

HYPERSONIC STABILITY DERIVATIVES FOR A STANDARD 10 DEGREE CONE

OTTO WALCHNER
FRANK SAWYER
BRIAN QUINN
HYPERSONIC RESEARCH LABORATORY

ERIC FRIBERG
FLUID DYNAMICS FACILITIES RESEARCH LABORATORY

D D C

AUG 24 1967

D

OFFICE OF AEROSPACE RESEARCH
United States Air Force

NOTICES

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto. .

- - - - - - - - -

Qualified requesters may obtain copies of this report from the Defense Documentation Center, (DDC), Cameron Station, Alexandria, Virginia. All others should apply to the Clearinghouse for Scientific and Technical Information.

ACCESSION for	
CFSTI	WHITE SECTION
DDC	BUFF SECTION
UNANNOUNCED	
JUSTIFICATION	
BY	
DISTRIBUTION/AVAILABILITY CODES	
DIST.	AVAIL. and or SPECIAL

- - - - - - - - -

- - - - - - - - -

Copies of ARL Technical Documentary Reports should not be returned to Aerospace Research Laboratories unless return is required by security considerations, contractual obligations or notices on a specified document.

ARL 67-0099

HYPERSONIC STABILITY DERIVATIVES FOR A STANDARD 10 DEGREE CONE

OTTO WALCHNER
FRANK SAWYER
BRIAN QUINN
HYPERSONIC RESEARCH LABORATORY

and

ERIC FRIBERG
FLUID DYNAMICS FACILITIES RESEARCH LABORATORY

MAY 1967

Project No. 7064

FOREWARD

This report was prepared by Otto Walchner, Frank Sawyer, Eric Friberg, and Brian Quinn of the Aerospace Research Laboratories under Project 7064.

The authors gratefully acknowledge the competent assistance of many of the Fluid Dynamics Facilities Research Laboratory's technicians and the Hypersonic Research Laboratory's secretaries.

ABSTRACT

This report describes experiments on the stability of an STA standard $10°$ cone. The free oscillation experiments on a sting mounted, open base model used an Optron tracker to register the model's oscillation about zero angle of attack. Values of the static (C_{m_α}) and dynamic $(C_{m_q} + C_{m_{\dot\alpha}})$ pitching moment stability derivatives are given for independent combinations of nine initial oscillation amplitudes (between $\frac{1}{2}°$ and $5°$), five reduced frequencies ($\omega d/2V$ between .0025 and .007), two pivot axis locations ($x_{cg}/l = 55\%$ and 60%), and two nominal Mach numbers ($M_\infty = 12$ and 14).

iii

NOMENCLATURE

A   base area of cone

C_m pitching moment coefficient, $M/q_\infty A d$

C_{m_α} $\partial C_m / \partial \alpha$

C_{m_q} $\partial C_m / \partial (q d / 2 v)$

$C_{m_{\dot\alpha}}$ $\partial C_m / \partial (\dot\alpha d / 2 v)$

d   model base diameter

f   frequency

I   moment of inertia

k   spring constant

l model length

M   pitching moment

M_∞ free stream Mach number

p_b model base pressure

p_∞ free stream static pressure

q   pitching speed

q_∞ free stream dynamic pressure, $\frac{1}{2} \rho V^2$

$R_{e_{\infty l}}$ Reynolds number based on model length and free stream conditions

r_b model base radius

r_N model nose radius

V   free stream velocity

x_{cg} pitch axis location aft of nose

α angle of attack

a_0 initial oscillation amplitude

γ ratio of specific heats

δ logarithmic decrement

Θ angular deflection

Θ_c cone half angle

ω circular frequency

Subscripts

$\dot{\Theta}$ $\partial / \partial \dot{\Theta}$

$\dot{a}$ $\partial / \partial \dot{a}$

INTRODUCTION

The dynamic stability of reentry configurations is a recurring subject at technical meetings and in the aerospace literature. The parameters involved in dynamic stability testing are numerous and researchers are currently reporting their observations of the effects of body geometry, Mach number, viscosity, mass addition, and many other variables. Two different experiments, each of whose object is to determine the effect of a given parameter on dynamic stability, are each designed around distinct measuring and data reduction techniques which themselves can be variables in the sense that they are capable of influencing the experimental results. Experiments with both small and large oscillation amplitudes have been reported, for example, using such diverse techniques as sting mounted wind tunnel models under forced or free oscillation, free flight models, and even wind tunnel models mounted on axles passing through their bodies.

The Supersonic Tunnel Association's Committee on Dynamic Stability (STA) has recommended a standard correlation model whose purpose is to assess the effects of experimental techniques and facilities on reported dynamic stability data. The model suggested by the STA is a 10 degree circular cone of spherical nose bluntness ratio, Nose Radius / Base Radius = 0.0167, pitched about an axis located 55% of the model length aft of the nose.

This report presents the results of an experimental investigation performed at the Aerospace Research Laboratories on the dynamic stability of an STA correlation model. The free oscillation experiments on a sting mounted, open base model used an Optron tracker to register the model's oscillation about zero angle of attack. The design of the experiment allowed testing at independent combinations of nine initial amplitudes ($a_0 = \frac{1}{2}$° to 5°), five

oscillation frequencies ($f = $ 8 to 26 hertz) and two pivot axis locations ($x_{cg}/l = $ 55% and 60%) at each of two nominal Mach numbers ($M_\infty = $ 12 and 14).

APPARATUS

1. WIND TUNNEL

The ARL 20-inch hypersonic wind tunnel, described fully in
Ref. 1, was used for the experiments. The facility is a blowdown,
free jet air tunnel with a 2000°R total temperature and capable of
operating for two minutes at a Reynolds number on the order of
6×10^5 per foot.

Two contoured nozzles were used in these experiments. Total
pressures for the nominal Mach 12 and 14 nozzles were around 1000
and 1500 psi, respectively. Figure 1 shows the Mach number distri-
bution for each nozzle and Figure 2 shows typical experimental
operating conditions.

2. MODEL AND FLEXURE

The model was constructed according to the recommended STA
specifications. Its physical dimensions may be seen in Figure 3. A
thin (.05") aluminum 10° conical shell was rigidly fastened to either of
two mounting devices which positioned the pivot axis either at 55% or
60% of the model length aft of the nose. Balance weights, shown in the
model schematic, Fig. 4, were adjusted to position the model's
center of gravity on the pitching axis. All of the model's moveable
parts were rigidly tightened so as not to absorb any vibrational energy.
The model could be displaced to nine different initial amplitudes between
(½° and 6°) by a sting-fixed, remotely actuated cam riding against
one of nine cone-fixed, interchangeable fingers. The shape of the
cam, which can be seen in Figure 4, assured a quick and clean
release from the initial displacement.

Base pressure was monitored by a Hastings gage connected to
a .078 inch orifice located approximately one inch aft the model in a

3

plane perpendicular to the pitch plane (Fig. 4). The gage signal was recorded on an x-y plotter.

Five torsion bar flexures, each with a different spring constant, were used at different times to anchor the model assembly to a rigid sting. Structural damping was minimized by machining each flexure from solid beryllium-copper stock followed by heat treatment (600°F for three hours, then air cooled) and by restricting the pitch oscillation to amplitudes which stressed the flexure to no more than the arbitrary level of 36,000 psi. The flexure geometry is shown in Figure 5 along with values of the spring constant for each flexure.

3. OPTRON TRACKER AND ATTENDANT EQUIPMENT

The pitching motion of the model was optically followed by an Optron tracker located outside of the tunnel test cabin and focused on a small illuminated target attached to the base of the model. An electrical signal whose voltage is proportional to the displacement of the target is generated by the optron tracker. The response is flat between zero and 7000 hertz. This signal, amplified by a Preston Scientific Model 8300 differential amplifier, was recorded on a Consolidated Electrodynamic oscillograph. With this equipment, a continuous time history of several hundred cycles of the oscillation was permanently recorded.

4

DATA REDUCTION EQUATIONS

Expressions relating the measurable quantities of frequency, logarithmic decrement and flow conditions to the static and dynamic pitching moment derivatives have been derived in Reference (3). Briefly,

$$C_{m_q} + C_{m_{\dot{\alpha}}} = - \frac{8}{\pi} \frac{d}{2} \frac{\omega_1}{V} \frac{I}{\rho A d^3} \left[\delta_1 - \left(\frac{\omega_2}{\omega_1}\right)^2 \delta_2 \right]$$

$$C_{m_\alpha} = - 8 \left(\frac{d}{2} \frac{\omega_1}{V}\right)^2 \frac{I}{\rho A d^3} \left[1 - \left(\frac{\omega_2}{\omega_1}\right)^2 \right]$$

where subscript 1 refers to wind on conditions and subscript 2 refers to wind off conditions.

EXPERIMENTAL METHOD

Oscillograph traces of the model's motion corresponding to a given initial amplitude and a given flexure were recorded for both wind-on and wind-off conditions. Values of the logarithmic decrements and frequencies were computed from not less than 200 cycles of the oscillation. Substitution of these values, along with both the model inertial and geometric characteristics and the tunnel flow parameters into the above equations readily yielded values for the static and dynamic stability derivatives.

The experimental program was run during the month of February 1966 and began with the Mach 12 nozzle and the 55% pivot axis location. Typically, the test procedure involved making a wind-off (approximately 1 mm Hg) run, and then a wind-on run using a given flexure and a given initial amplitude finger. After the wind-on run, the model was cooled and the finger replaced by another one. This procedure was continued until all of the necessary fingers had been used. The flexure was then changed. Once all of the flexure-finger combinations had been exhausted, the same combinations were repeated using the Mach 14 nozzle. This same procedure was followed subsequent to repositioning the pitch axis at the $x_{cg}/l = 60\%$ position.

In all instances, the base pressure ratio p_b/p_∞ was less than unity and typically around 80%.

RESULTS AND DISCUSSION

In Figures 6 through 9, the experimental data obtained for both Mach numbers and both x_{cg}/ℓ positions plotted against the initial pitch amplitude can be seen. No dependence of the static and dynamic stability derivative on the initial amplitude can be seen within the scatter of the data, so that if such a dependence exists, it is a higher order effect.

Values of the static derivative, C_{m_α}, given by flexure number 5 lie below those given by the other flexures in Figures 7 and 9. This discrepancy was unfortunately not discovered until the experimental program had been completed and the wind tunnel equipped to run another project. It was not until nearly a year later that the experiment using flexure number 5 could be repeated. On 9 January 1967, two runs were made: one with flexure number 2, the other with flexure number 5. Results of these experiments are tabulated below.

flexure	$\dfrac{\omega d}{2V}$	$C_{m_q} + C_{m_{\dot\alpha}}$	C_{m_α}	$(\alpha_0)^\circ$	x_{cg}/ℓ	M_∞
2	.00351	-2.65	-.50	2	.6	14.32
5	.00678	-2.70	-.485	2	.6	14.32

TABLE I

The repeatability of the flexure number 2 data was satisfactory and the value of C_{m_α} with flexure number 5 was more in line with the static derivative obtained with the other flexures. Although this might point to a procedural error in the February 1966 tests with flexure number 5, the authors are not aware of the error but state simply that the flexure number 5 data are questionable and not subject to further discussion.

Average values of the dynamic and static pitching moment derivatives have been tabulated and compared with the Newtonian impact ($C_p = 2 \sin^2 \Theta_c$) predictions in Table II. The columns labeled SCATTER give the half width of the band that contains all data points. For example, with $M_\infty = 12.55$ and $x_{cg}/\ell = 0.55$ all $C_{m_q} + C_{m_{\dot{\alpha}}}$ data points are within $\pm 12\%$ of the average value, -3.04. As expected, the

M_∞	x_{cg}/ℓ	$(C_{m_q}+C_{m_{\dot{\alpha}}})_{avg}$	Scatter %	$(C_{m_\alpha})_{avg}$	Scatter %	$C_{m_{q_{Newt.}}}$	$C_{m_{\alpha_{Newt.}}}$
12.55	.55	-3.04	12.0	-.73	5.5	-2.24	-.663
14.24	.55	-2.98	16.6	-.72	8.3	-2.24	-.663
12.55	.60	-2.74	7.25	-.48	9.4	-1.94	-.379
14.24	.60	-2.62	5.72	-.444	10.0	-1.94	-.379

TABLE II

Newtonian impact theory consistently underpredicts both the static and dynamic stability derivatives.

REFERENCES

1. Tepe, F. R., Brown, D. L., Token, K. H., and Hoelmer, W., "Theoretical Operating Ranges and Calibration Results of the ARL 20-Inch Hypersonic Wind Tunnel," Aerospace Research Laboratories' Report No. ARL 63-189, 1963.

2. Daum, F. L., "The Condensation of Air in a Hypersonic Wind Tunnel," Aerospace Research Laboratories' Report No. ARL 63-42, 1963.

3. Walchner, O., Sawyer, F. M., and Koob, S. J., "Dynamic Stability Testing in a Mach 14 Blowdown Wind Tunnel," Aerospace Research Laboratories' Report No. ARL 64-221, 1964.
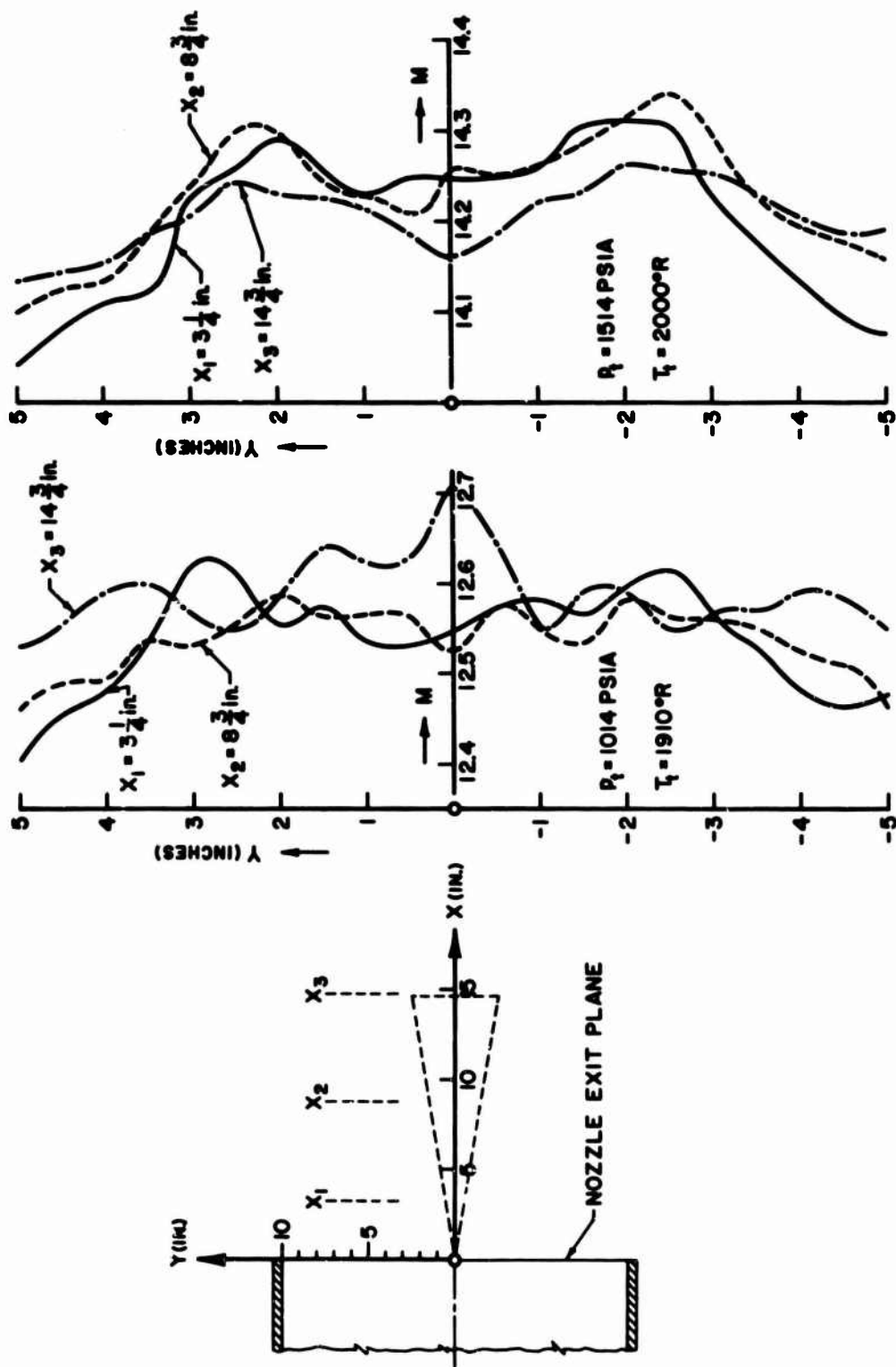
Figure 1. Mach Number Distribution for the Mach 12 and the Mach 14 Nozzles

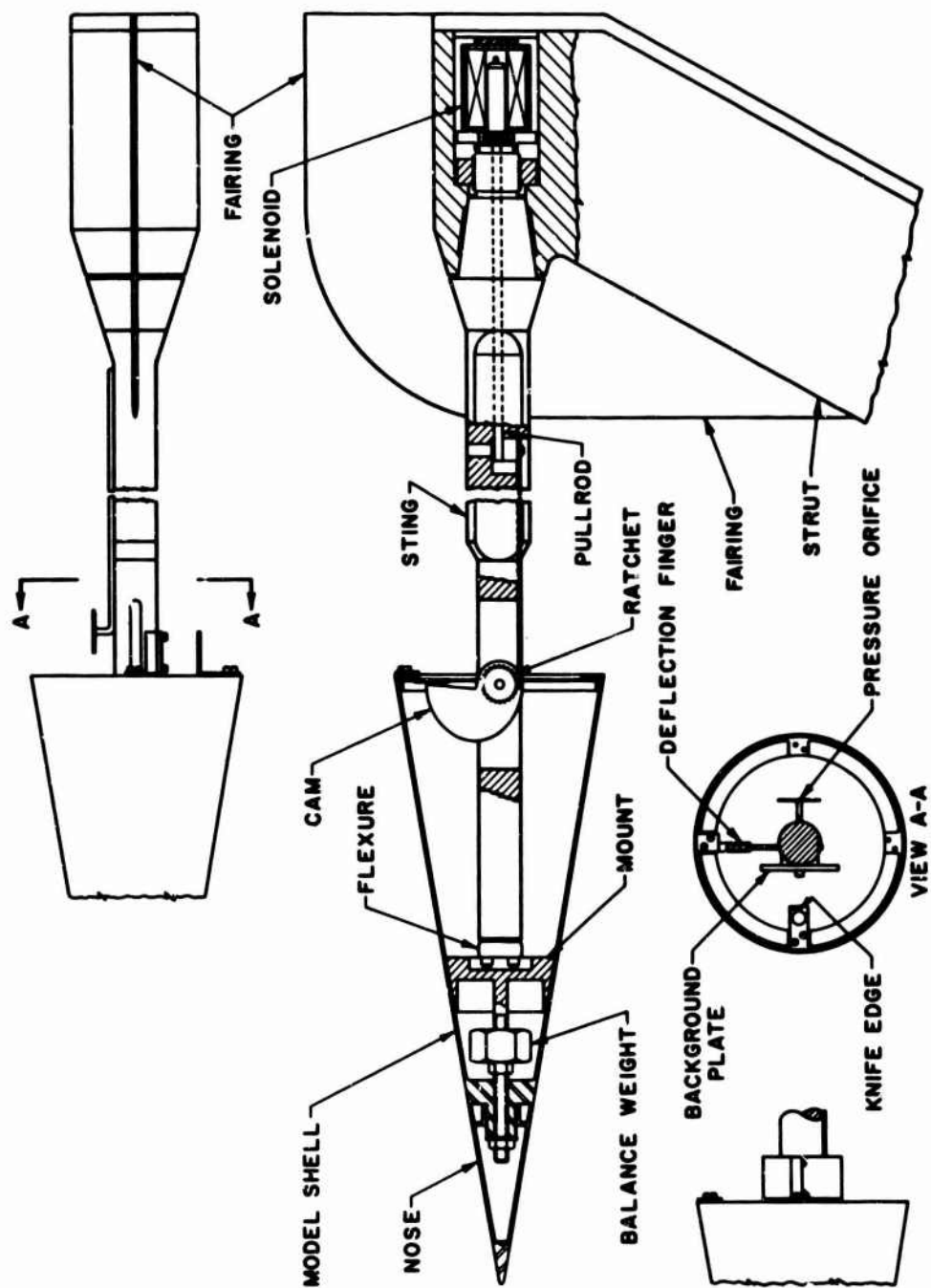16
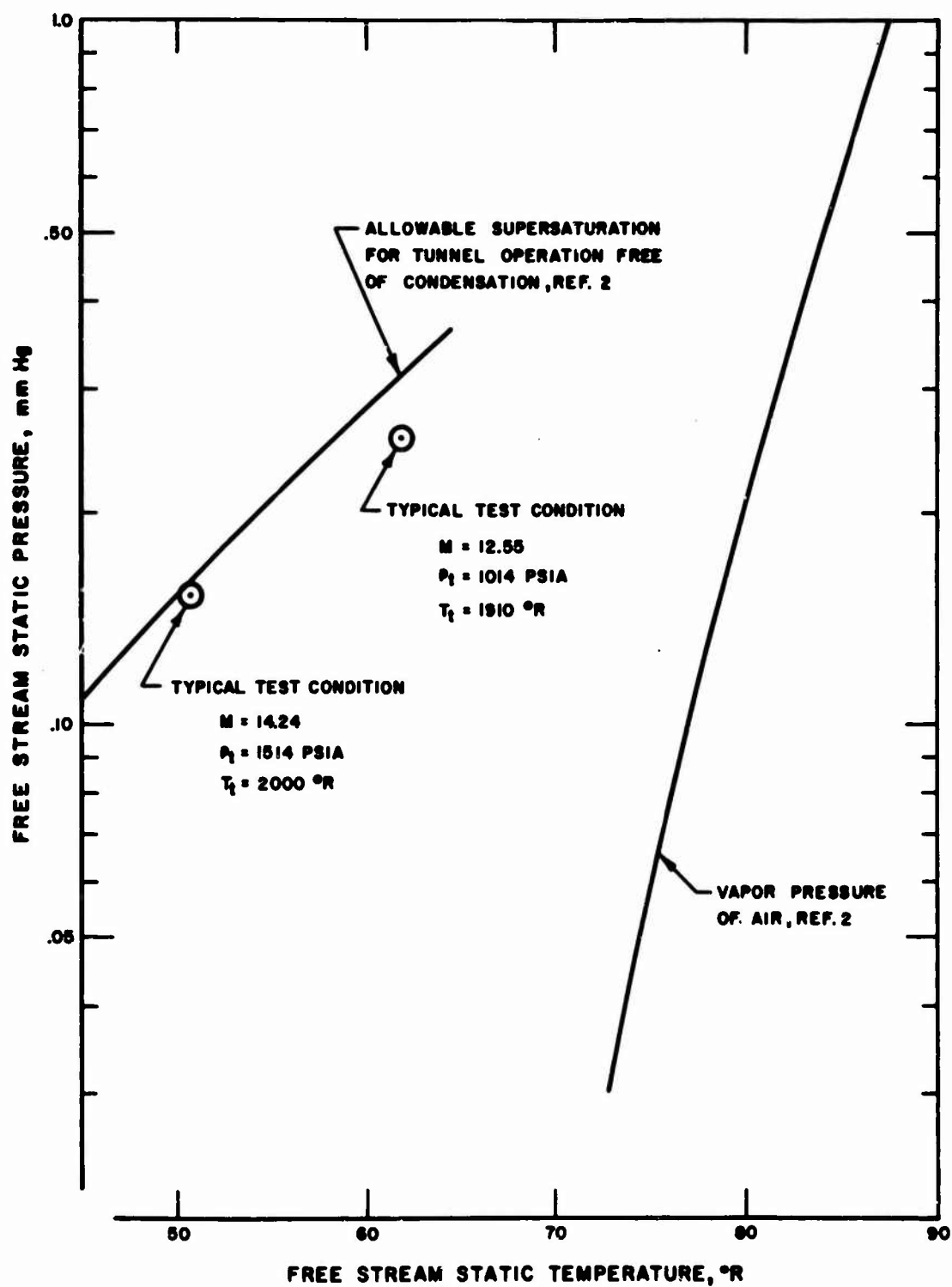
Figure 2.   Experimental Test Conditions

11

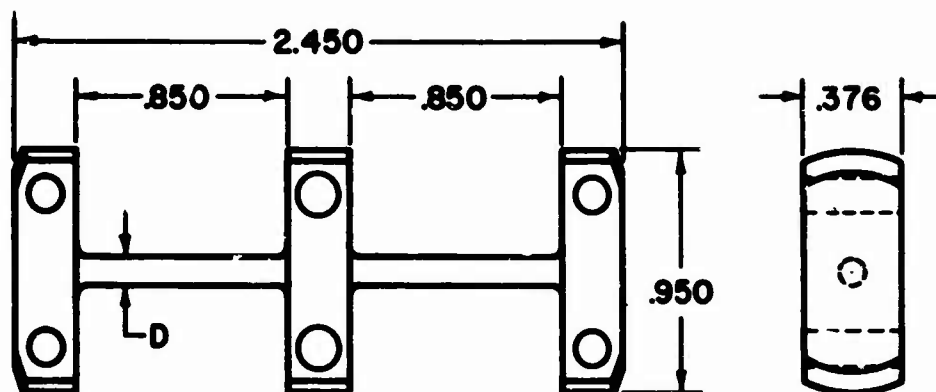Figure 3. Model and Sting Dimensions

CONFIGURATION	$X_{c.g.}/L$
1	0.55
2	0.60

12

Figure 4. Model Schematic

13

DIMENSIONS IN INCHES

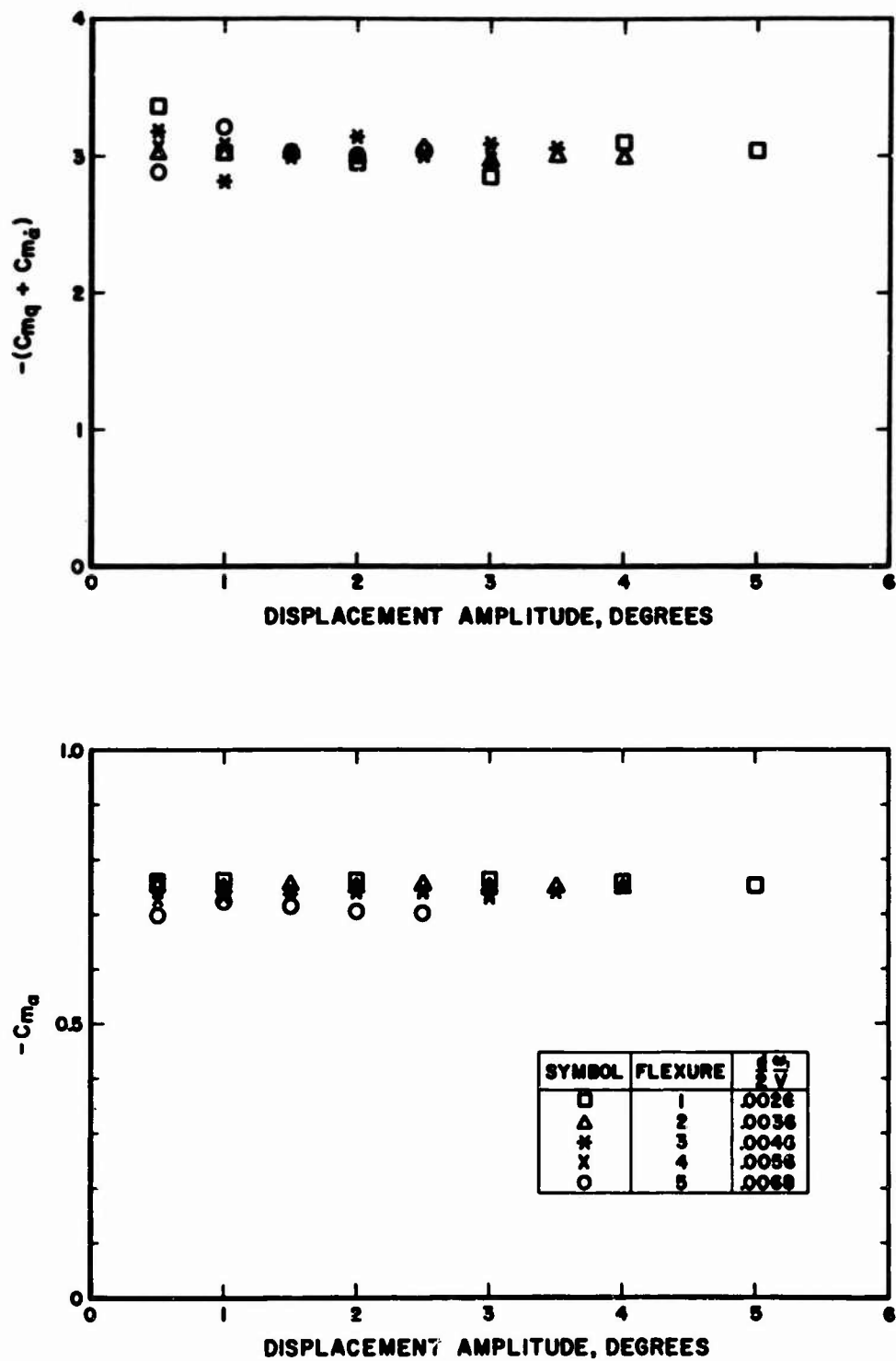| FLEXURE	D (Inches)	k (Ft.-Lb./RAD.)
1	.088	8.02
2	.108	18.34
3	.125	33.14
4	.139	50.24
5	.153	75.12

Figure 5. Flexures and Spring Constants

14

Figure 6. Experimental Dynamic $(C_{m_q} + C_{m_{\dot\alpha}})$ and Static (C_{m_α}) Stability Derivatives. $M = 12.55$, $x_{cg}/l = .55$
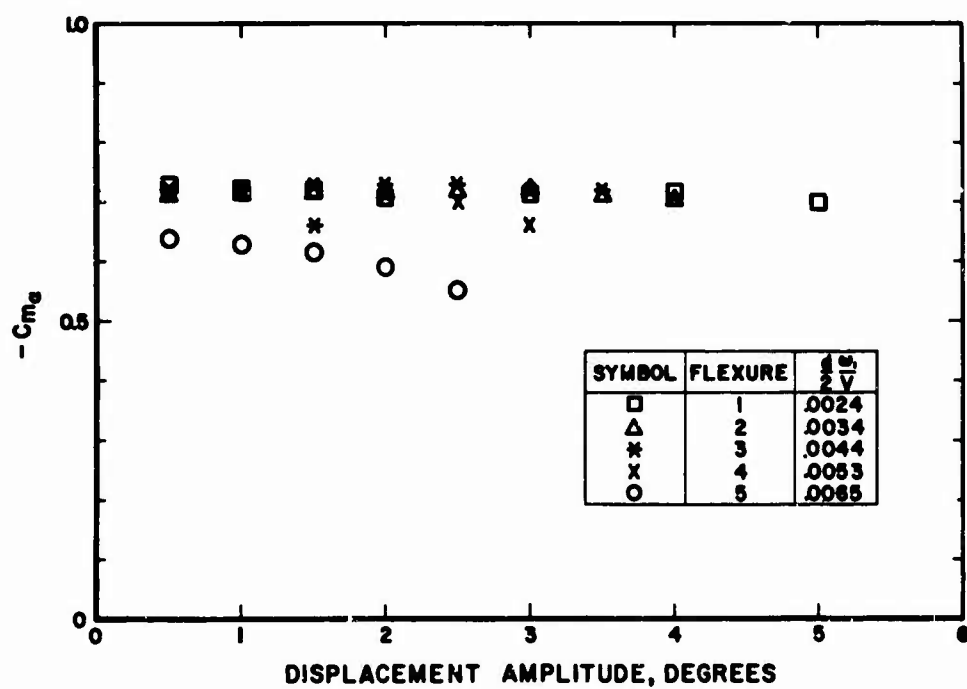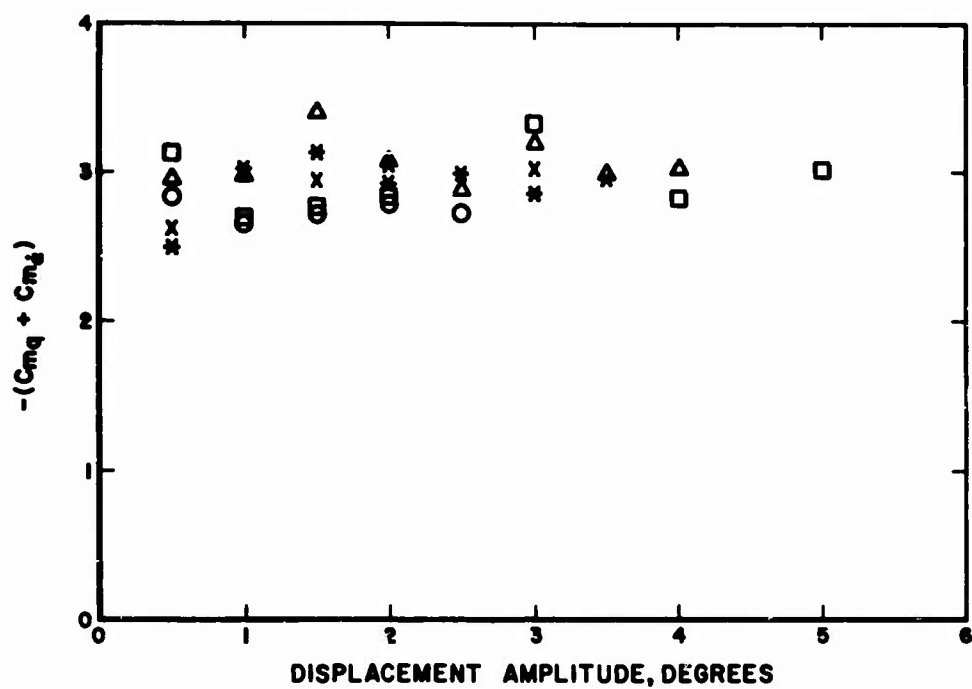
Figure 7. Experimental Dynamic $(C_{m_q} + C_{m_{\dot\alpha}})$ and Static (C_{m_α}) Stability Derivatives. $M = 14.24$, $x_{cg}/\ell = .55$

16
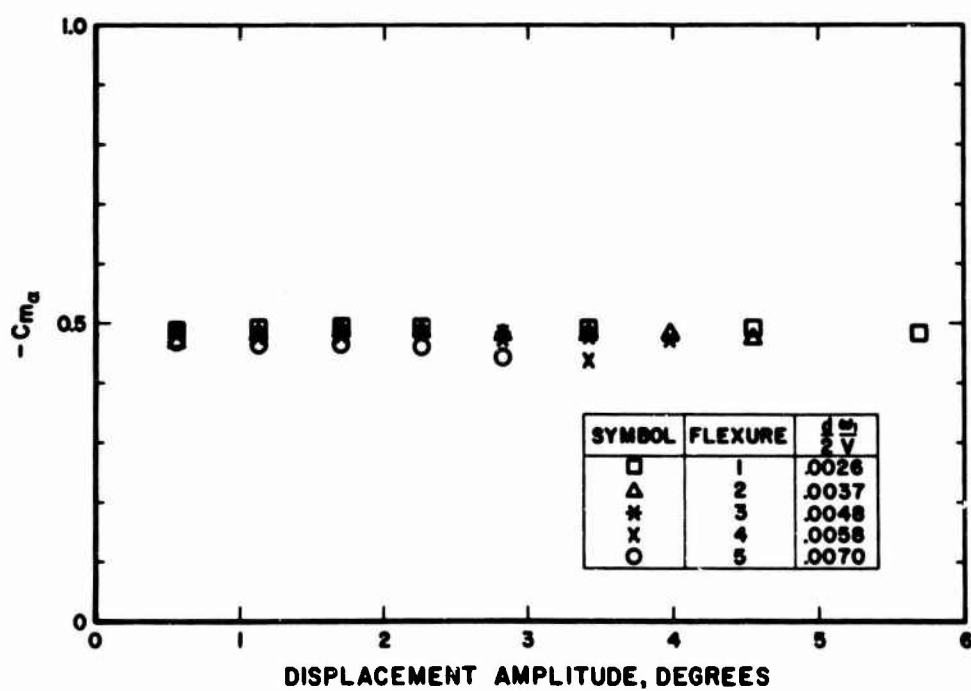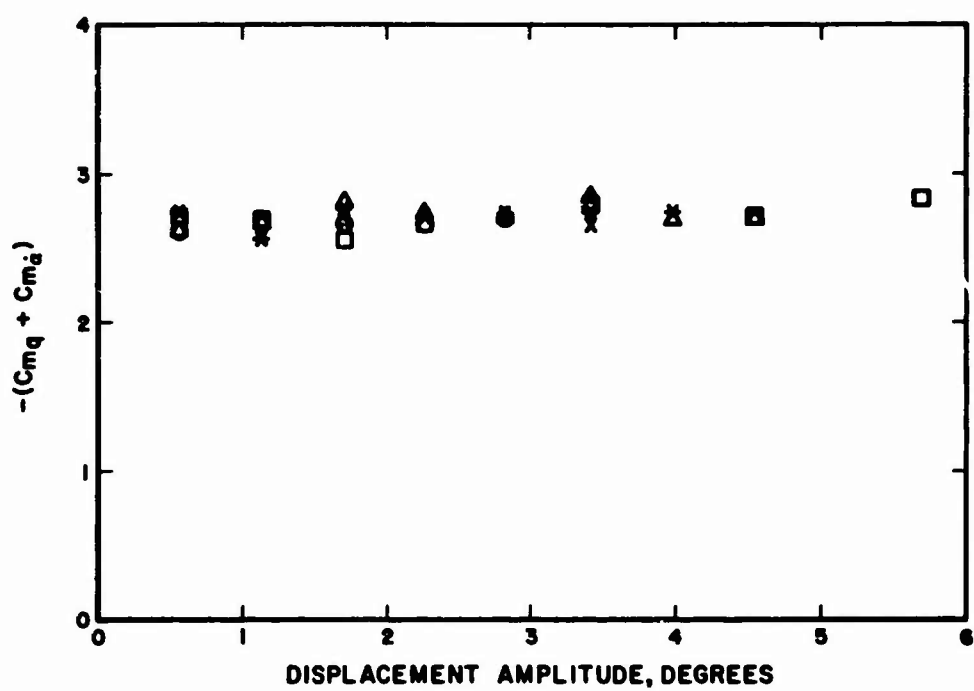
Figure 8. Experimental Dynamic ($C_{m_q} + C_{m_{\dot{\alpha}}}$) and Static ($C_{m_\alpha}$) Stability
Derivatives. M ≈ 12.55, x_{cg}/l = .6
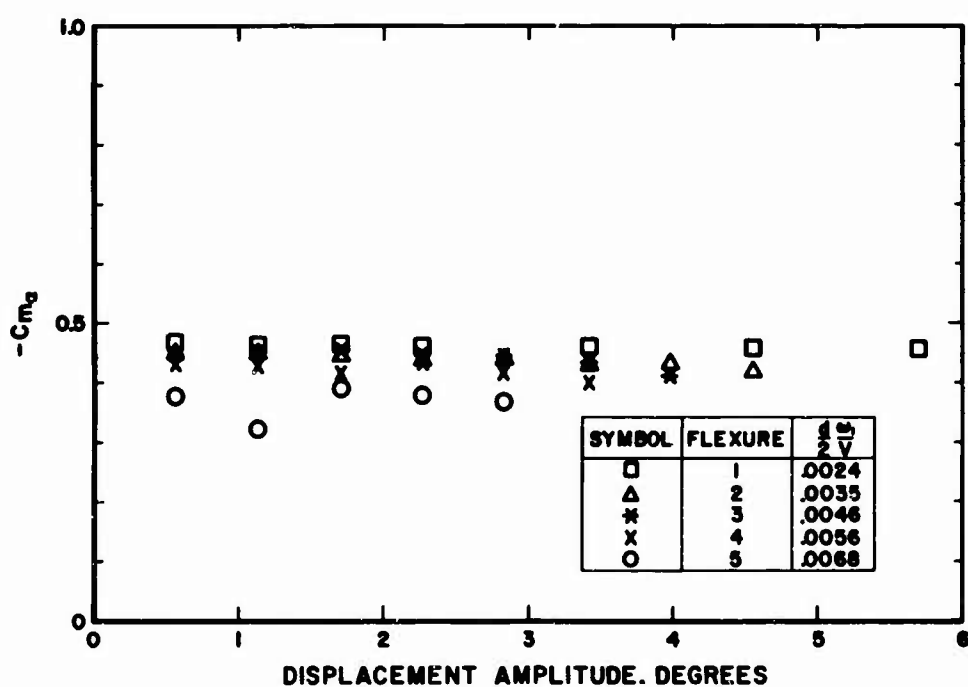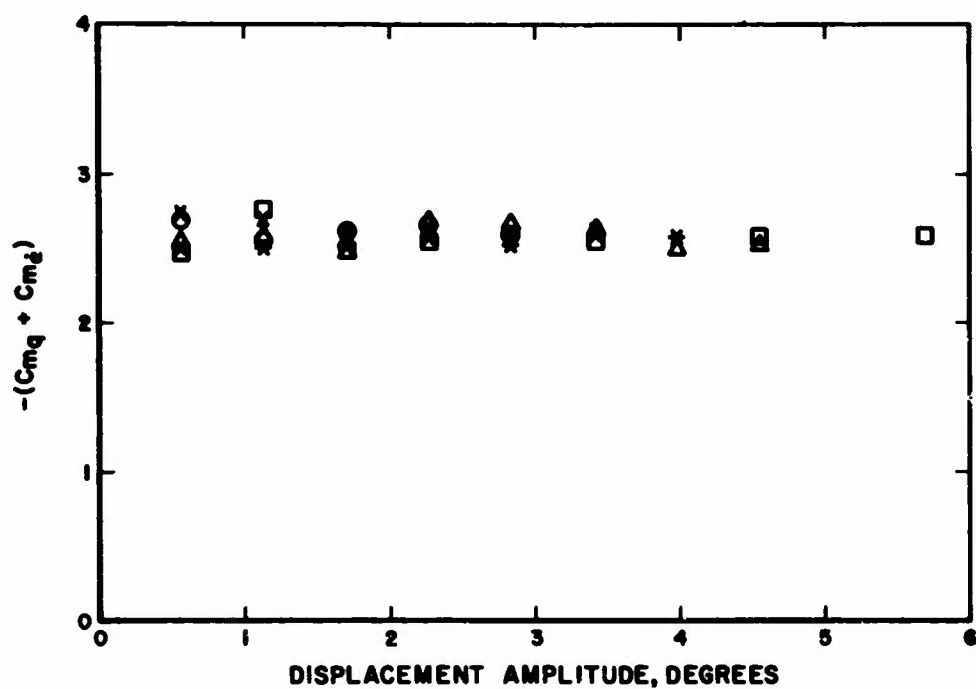
Figure 9.   Experimental Dynamic $(C_{m_q} + C_{m_{\dot\alpha}})$ and Static (C_{m_α}) Stability

Derivatives.   M =   14. 24, $x_{cg}/l =$ .6

18

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION
Hypersonic Research Laboratory Aerospace Research Laboratories Wright-Patterson Air Force Base, Ohio 45433	Unclassified 2b. GROUP

3. REPORT TITLE

Hypersonic Stability Derivatives for a Standard 10 Degree Cone

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Scientific.   Final.

5. AUTHOR(S) (Last name, first name, initial)

Otto Walchner
Frank Sawyer
Eric Friberg
Brian Quinn

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
May 1967	24	3

8a. In-house research	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. 7064-00 01	
c. DoD Element 61445014	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d. DoD Subelement 681307	ARL 67-0099

10. AVAILABILITY/LIMITATION NOTICES

1. This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
TECH OTHER	Aerospace Research Laboratories (ARR) Office of Aerospace Research Wright-Patterson AFB, Ohio 45433

13. ABSTRACT

This report describes experiments on the stability of an STA standard 10° cone. The free oscillation experiments on a sting mounted, open base model used an Optron tracker to register the model's oscillation about zero angle of attack. Values of the static (C_{m_α}) and dynamic ($C_{m_q} + C_{m_{\dot{\alpha}}}$) pitching moment stability derivatives are given for independent combinations of nine initial oscillation amplitudes (between $\frac{1}{2}°$ and 5°), five reduced frequencies ($\omega d/2V$ between .0025 and .007), two pivot axis locations ($x_{cg}/l = 55\%$ and 60%), and two nominal Mach numbers ($M_\infty = 12$ and 14).

DD FORM **1473** 1 JAN 64

•4. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
dynamic stability						
standard 10° cone						
hypersonic stability						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers (*either by the originator or by the sponsor*), also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those

imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
_____ ."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
_____ ."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
_____ ."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring (*paying for*) the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS), (S), (C),* or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

GPO 885-551